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Local–Global Interface as a Key Factor in the Catching Up of Regional Innovation Systems: Fast versus Slow Catching Up among Taipei, Shenzhen, and Penang in Asia

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Abstract

This study raises the question of why economic performance and growth trajectories differ among three Asian regions, namely, Taipei, Shenzhen, and Penang. Among them, Taipei the most developed, whereas Penang is the least developed. The question is also why Shenzhen is catching up fast with Taipei, whereas the catching-up speed of Penang is slow. From a Schumpeterian perspective, this study addresses these questions based on the divergent nature of regional innovation systems (RIS) in the three regions by focusing on the local–global interface. Results reveal that Taipei show the highest and increasing level of intra- and inter-regional localization of knowledge and a low and decreasing level of internationalization (the degree of relying on foreign knowledge). Shenzhen replicates this trajectory of Taipei more closely than Penang that continue to be dependent upon foreign knowledge sources. Penang also increases very slowly its intra- or inter-regional localization of knowledge. Second, the main carrier and ownership of innovation in Taipei have shifted from foreign MNCs to indigenous firms. Shenzhen closely replicates this phenomenon, but Penang continuously relies on foreign MNCs. Third, Taipei has an increasing and high value of technological diversification, which is closely followed by Shenzhen but not by Penang. These findings help us identify a dynamically catching-up RIS, which can be characterized by a steady increase in intra-regional localization, a decrease in internationalization, an increase in local innovation ownership, and an increase in technological diversification. Its implication for policies is the importance of eventually increasing the localization of innovation and its ownership after these regions learn from foreign knowledge sources.

Keywords: regional innovation systems, Taipei, Shenzhen, Penang, catching-up, local-global interface
JEL codes: O31 O32 O33 R11 R58

1. Introduction

Although the economic performance of latecomers has been uneven since World War II, several economies in East Asia have achieved rapid growth and sound equity, which is described in World Bank's *East Asian Miracle* report (1993). This report and most studies on East Asian economics have focused on the role of governments versus markets in catching-up development (Amsden, 1992; Chang, 1994, 1993; Wade, 1992). Recent studies have shifted their focus on innovation as the key engine of catching-up growth, as some of the East Asian economies move to later or middle-income stages of development when innovation has become a binding factor more than the prices or costs at earlier stages (Lee, 2013; Mazzoleni and Nelson, 2007).

Innovation-focused studies have adopted the framework of the national innovation system (NIS), which is one of the key concepts in Schumpeterian economics (Freeman, 1987; Lundvall, 1992; Nelson, 1993). Lundvall (1992) defined NIS to comprise elements and relationships that interact in the production, diffusion, and use of new and economically useful knowledge in a nation. Thus, scholars from the Schumpeterian School observed that differences in NIS may lead to variations in innovation performance and economic growth. However, the question of why innovation activities and economic development are unevenly distributed over space, even in the same nation, remains unanswered (Asheim et al., 2019: 1). This question justifies the concept of regional innovation systems (RIS) and the analysis of innovation and economic performance of regions and cities. Cooke et al. (1998: 1581) defined RIS as a region-level "system in which firms and other organizations are systematically engaged in interactive learning through an institutional milieu characterized by local embeddedness."

This study brings this question of uneven development of regions in the context of Asia. While Asian economic takeoff has been associated with international integration via FDI or MNCs, we still see some divergence among regions, such as Shenzhen versus Penang. Shenzhen in South China was one of the first special economic zones to attract FDI and has spearheaded the economic development of China since the 1980s. Penang in Malaysia has also been one of the first regions in Southeast Asia to attract FDI since the early 1970s, but its growth was somewhat slow compared to Shenzhen. A size of the surrounding nation might not be the dominant factor of this difference, given that Taipei has also achieved fast growth while relying on FDI since the 1960s, despite that it is a city in a small island of Taiwan.

Among the three regions, Taipei has the highest GDP per capita. Shenzhen and Penang caught up with Taipei at different speeds (i.e., Shenzhen catches up rapidly, but Penang catches up slowly). These two region's innovation performances also differ. Shenzhen is more innovative than Penang in terms of the number of US-filed patents. This correlation between innovation and economic performance in the three regions served as a motivating justification of this study to apply the RIS framework and explain the divergent economic performance of the three regions. Thus, a comparison of these regions in Asia would be an interesting case in terms of the broad framework of uneven development of regions (Yeung, 2021), given a common initial condition of growth dependent on foreign direct investment (FDI) at their early development stage.

Various studies on cities and sub-national units in East Asia have applied the concept of RIS (Hassink 2001; Wong et al., 2018; Yang, 2015; Yoon et al., 2015). In comparison with previous studies on RIS in Asia, this study develops and adopts the patent-citation-based measurement and analysis of RIS. Furthermore, among the various dimension of the RIS, this study focuses on the local–global interface, namely, where and how local actors and their learning interact with foreign actors and knowledge sources. As extensively discussed in the GPN (global production network) literature (Yeung, 2021; Yeung, 2019; Yeung and Coe, 2015), diverse modes of coupling, decoupling, or recoupling with GPN has been considered as the key causal mechanism for uneven performance of regions. Thus, the focus of this study can be justified because the three regions, as latecomers from emerging economies (EEs), share the common initial condition of heavy reliance on FDI at their early stage of development. However, the question is "why and how" these regions have evolved to correspond to divergent outcomes eventually.

This paper tries to answer this question in terms of the contrast between the mature or advanced versus peripheral or immature RIS, where the latter is characterized to be heavily reliant on external knowledge, given its lack of indigenous knowledge base (Asheim et al., 2019: 73; Rodriguez et al., 2014). The analysis using patent data shows that Taipei has been successfully upgraded into an advanced RIS by reducing its reliance on foreign knowledge and promoting indigenous firms. Shenzhen has been replicating Taipei's trajectory more closely than Penang, which has continuously relied on foreign knowledge sources and has failed to generate indigenous firms.

Thus, one of the first contributions of this paper is to characterize the mature versus immature and catching-up RIS. Mature or advanced RIS in high-income economies is characterized by a high level of intra- and inter-reginal localization of knowledge, a decent level of the local ownership of innovations, a high degree of technological diversification, and a wide dispersion or decentralization of innovators. However, immature or backward RIS has opposite characteristics. In comparison, a dynamically catching-up RIS or upgrading process of RIS can be characterized by a steady increase in intraregional creation and diffusion of knowledge, a decrease in internationalization, an increase in the local ownership of innovation, and an increase in technological diversification, but not necessarily a decentralization of innovator distribution.

Through the analysis of the RIS of three regions, this paper also contributes to the literature on RIS by identifying the increasing localization of knowledge creation and ownership as the key factor of upgrading a region in emerging economies. While some of the existing studies have also emphasized the role of the eventual emergence of indigenous innovation and firms in latecomer development (Amsden and Chu, 2003; Lebdioui et al., 2021; Lee et al., 2021b; JD Lee et al., 2021; Yoruk, 2019), their focus or unit of analysis tends to be a nation or a firm and not to conduct analysis of detailed mechanism of knowledge creation and diffusion using patent-driven variables.

The remaining parts of this paper are arranged as follows. Section 2 provides the basic profiles of the three regions (Taipei, Shenzhen, and Penang) and briefly discusses their catching-up performance. Section 3 presents the related literature, hypotheses, and theoretical framework for analysis. Section 4 describes the USPTO patent dataset and the manner by which key RIS variables are defined and measured using patent data. It basically addresses the question of "why" some regions have achieved a better performance in terms of the results associated with the key variables. Section 5 address the question of 'how' some regions have been able to do better and discusses alternative models of catching-up RIS to differentiate slow and fast catching-up modes. Section 6 provides the summary of the key findings and concluding remarks.

2. Profiles of the Three Regions and Catching-up Performance

Taipei, Shenzhen, and Penang belong to the dynamic economies in Asia, namely, Taiwan, China, and Malaysia, respectively. They can also be regarded to be representing the fast economic growth of the respective economies.

Taipei has served as the central city that has highly contributed to the overall economic growth of the Taiwan economy. Taipei has been not only the center of Taiwan enterprises but also the headquarters of foreign multinational corporates. (Huang, 2008). Several foreign MNCs established their headquarters or subsidiaries in Taipei as early as the late 1950s. But it is mostly since the 1960s that a vast majority of export-based manufacturing headquarters flocked to Taipei in order to take advantage of the administrative and policy support from the central government, as Taiwan started to adopt more aggressively the mode of export-oriented industrialization (Chou, 2005; Hsu, 2005; Li et al., 2016). However, the weight of foreign firms has steadily decreased as some indigenous firms have grown into large giants, such as Acer (Amsden and Chu, 2003; Hsu, 2005). In the present study, the term "Taipei City" covers the former Taipei County (New Taipei) and the former Taipei City proper, with its formal merging and recognition in 2010.[1] Table 1 shows that its population grew slowly from 2.2 million in 2000 to 2.6 million in 2017.

Shenzhen is one of the first four special economic zones that represent the open door policy of China initiated by Deng Xiaoping. Although it used to be the home of labor-intensive manufacturing

[1] As Taipei City and Taipei County were confoundingly used in patent data, we designate both Taipei City and New Taipei City as "Taipei City" in our analysis below.

that utilized low-cost labor and supplied to Hong Kong, it has grown into a high-tech region (Chen and Kenney, 2007; Yang, 2015). In reflecting its prosperity, Shenzhen's population has increased from less than 5 million in the 1990s to more than 12 million in 2017 (Table 1).

Since 1972, Penang has been one of the earliest manufacturing hubs in Asia to attract foreign MNCs because of its low labor costs and low taxes in areas involving diverse electronic parts and components (Ariffin and Figueiredo, 2004; Diez and Kiese, 2006; Rasiah, 1988). MNCs operations in Penang started since 1972 when Bayan Lepas free trade zone was launched and hosted initially the seven MNCs.

One of the common features of the three regions is that they initially invited and promoted FDI through MNCs by setting industrial parks, such as the Free Industrial Zone (FIZ) in Penang in 1972, and then the Special Economic Zones in Shenzhen in 1980 (Hsu, 2005; UNDP, 2006). In particular, despite its later start than Penang, Shenzhen has shown a faster long term growth in its income and the number of patents (Table 1 and Figure 1), which makes an interesting puzzle to pursue in this study.

(Table 1; Figures 1A and 1B)

Figures 1A and 1B show the trends of per capita GDP in each region and its per capita GDP relative to that in the US. First, they have a decent record of economic growth and catching up with the level of the US. Among them, Taipei has the highest level, and Penang has the lowest level. Since 2000, Taipei has successfully caught up with a per capita GDP of over 80% of that of the US. Its per capita GDP is more than $50,000 in PPP terms, and it reached almost 97% of that of the US in 2017. In 2017, the per capita GDP of Shenzhen was $39,245 in PPP terms, ranking the second among the three regions, and this level was approximately 72% of the per capita GDP of the US. In 2017, the per capita GDP of Penang was $27,569 and reached more than 50% of that of the US. It was even less than 40% before 2000. In this sense, all the three regions have shown a strong record of catching up although their catching-up speeds differ. In particular, the catching-up speed of Shenzhen is faster than that of Penang.

The middle-income trap is defined as the per capita GDP of a country/region remaining within 20%–40% for several decades (World Bank 2012). On the basis of this definition, all the three regions, including Penang since 2006, have escaped the middle-income trap. However, some differences have emerged. For instance, Shenzhen more rapidly catches up with Taipei than Penang does. The gap between Shenzhen and Penang was about 10% point in terms of the gap with the US level in the early 2000s, but it increased to about 20% points by the mid-2010. Therefore, Shenzhen has reached about 70% of the US level, whereas Penang is just above 50% of the US level.

This study explores the number of patents, especially those registered in the US for fair comparison. Figure 2A shows that the number of the US patents registered with the inventor's address in Taipei has dramatically increased since the late 1990s. In 2017, the number of patents was 3,780.

Similarly, this parameter has remarkably increased since the late 2000s in Shenzhen, i.e., from nil in the 1990s to about 2,500 in 2017. However, such a rapid catching up is not realized in Penang, whose number of patents is only 100. This comparison of the three regions remains valid in terms of patent count per person (Figure 2B).

(Figures 2A and 2B)

This discussion raises one interesting question, that is, "why does Shenzhen catch up with Taipei faster than Penang?" This study aims to explain the sources of this performance gap among the regions by analyzing their RIS beyond the simple counts of patents. More specifically, we explore the possibility of different development trajectories among the three regions in terms of the different local–global interfaces or the role of indigenous firms and their contribution to innovation in these regions.

3. Theoretical Framework and Hypotheses

1) From NIS to RIS

Since the late 1980s, scholars such as Freeman (1987), Lundvall (1992), and Nelson (1993) have proposed the concept of NIS. NIS focuses on efficiency in knowledge production, diffusion, and use of knowledge and its effectiveness in translating innovation into economic performance. Various dimensions of NIS have been measured and examined to analyze its relationship with economic growth (Archibugi and Coco, 2004; Castellacci, 2008, 2011; Edquist, 1997; Fagerberg and Srholec, 2008; Fagerberg and Verspagen, 2002). Measurements may involve different variables to capture diverse economic aspects, including techno-economics, political institutions, IT-related infrastructure, openness, and financial systems. Although the broad scope of such measurements may be advantageous, it may blur the boundaries between innovation and other economic aspects.

Further studies have used a narrowly focused patent-driven measure of NIS that is close to its original definition, which highlights the mechanisms to generate, diffuse, and use knowledge (Lundvall, 1992). Thus, Lee (2013) employed a single dataset comprising patents filed in the US to measure and analyze the NIS worldwide and focused on five component variables that represent knowledge localization (diffusion), technological diversification, decentralization, originality, and cycle time of technologies.[2] This study also measures and uses some of these indices at the regional level. Lee et al. (2021a) identified several varieties of NIS and two alternative pathways to grow beyond the middle-income stage; for instance, they explored the imbalanced and balanced, catching-up NIS.

[2] Most of these NIS variables were first proposed by Jaffe et al. (1993) and Jaffe and Trajtenberg (2002), but they considered different contexts other than catching up by latecomers.

Although the NIS analysis has been successfully applied to examine national-level economic activities, the nature of innovation systems can be heterogeneous in terms of regions, even in the same country (Asheim et al., 2019: 1). Some regions may have a higher innovation level than the country where they are located. Thus, the RIS approach is necessary to explain the heterogeneous geographical distribution of innovation in a given territory and construct policies enhancing the innovation capability of regional economies (Isaksen et al., 2018). Recently, numerous studies have focused on RIS (Asheim, 1995; Cooke, 1992; Porter, 2000; Uyarra, 2010; Werker and Athreye, 2004). On the basis of previous studies on theoretical underpinning, quantitative approaches have been used to study the efficiency of different kinds of regional innovation systems (Fritsch and Slavtchev, 2011; Zabala-Iturriagagoitia et al., 2007).

One important issue in RIS studies includes the typology and dynamic change in RIS (Asheim, 1998; Asheim and Gertler, 2006; Asheim et al., 2019; Cooke, 2005, 2001, 1998; Wong and Lee 2021) and a variety of criteria and perspectives on RISs. Regarding this issue, the current study raises the issue of upgrading RIS in emerging countries and asks the following questions: What is the nature of RIS in emerging countries? What are their dynamic changes over time in their effort to catch up with those in advanced economies?

2) RIS of Emerging Economies

Studies have proposed several alternative approaches to RIS typologies, depending on their interests and focus. Asheim (1998) proposed three types of territorially embedded RIS, territorially networked RIS, and regionalized national innovation systems. Cooke (2001) proposed two types, namely, entrepreneurial and institutional RIS. Others proposed a place-based leadership approach (Benneworth et al., 2017; Beer and Clower, 2014).

In the context of emerging economies, the concept of peripheral or immature RIS is characterized to be heavily reliant on external knowledge, given its lack of indigenous knowledge base (Rodriguez et al. 2014; Asheim et al. 2019: 73). Similarly, the concept of the *dirigiste* systems is proposed to refer to a low level of regional embeddedness (Park and Markusen, 1995; Hassink, 2001). The latecomers' reliance on foreign knowledge makes sense, given that typical latecomer economies tend to achieve economic growth by relying on FDI and learning from foreign MNCs (Bernardes and Albuquerque, 2003; Lebdioui et al., 2021; Amsden and Chu, 2003). This pattern indicates that latecomer regions show a low level of patenting at early stages and more citations of foreign patents than indigenously-owned patents, even after they start to conduct their own R&D and file patents (Wong and Lee 2021).

This characterization of RIS in emerging economies in terms of low-level indigenous knowledge is consistent with national-level studies involving the NIS concept of emerging or catching-up economies. Lee (2013) and Lee et al. (2021a) also found that one of the important attributes of NIS of an economy showing a performance of rapid catching up is the initially low and increasing level of knowledge localization or the degree of intranational creation and diffusion of knowledge, as measured by national-level self-citations. Therefore, during the stage of low-level economic development, emerging economies are likely to rely on knowledge from foreign or more advanced economies, rather than creating and diffusing their own indigenous knowledge. During the stage of economic catching up, latecomer economies can adopt foreign knowledge to a local context to conduct imitative creation (Kim, 1997) and move on to the stage of proper innovation, which is characterized by the increasing level of knowledge localization and local ownership.

This sequence of the initial reliance on foreign knowledge and the increasing level of knowledge localization and local ownership is consistent with the sequence of “In and Out then In again” in terms of the GVC participation (Lee et al., 2018) or that of “coupling, decoupling, and recoupling” in GPN literature (Yeung and Coe, 2015; Yeung, 2019). This sequence implies that local firms are initially engaged or coupled with the MNC flagship companies leading a GPN/GVC, wherein they may learn from the participating GPN, and some of them seek to increase domestic value-added or build indigenous value chains leading to some degree of decoupling in GPN. In this sequence, the final stage may be when local firms join the GVC/GPN again after they build some level of their own or indigenous technological capabilities (Lee et al., 2018; Yeung and Coe, 2015).[3]

Yeung (2019, 2021) proposed this coupling and decoupling as the causal mechanism of different outcome or uneven development of regions. In the context of this research, this specific process and mechanism of “localization of knowledge creation and ownership” would be the causal mechanism of more successful or less successful performance of the innovation systems of different regions of Taipei, Shenzhen, and Penang. Thus, our answer to the question of ‘why’ Shenzhen has been doing better than Penang is that the former has increased more rapidly the degree of localization of knowledge creation and ownership than the latter, and that in the former region indigenous firms have eventually emerged to become the dominant player of knowledge creation and diffusion within the region, whereas they used to rely on foreign firms as the sources of knowledge.

As discussed in Yeung (2021), such eventual importance of localization of knowledge creation and ownership as a part of region-specific relational assets is consistent with the influential work of Storper (1993) and the later literature of evolutionary geography (Boschma and Frenken, 2006). However, we observed that the region-specific relational asset can be realized only after the local firms are coupled with the GPN/GVC at their early learning stage. In terms of this dynamic change or sequence, this view is consistent with the literature GPN (Yeung, 2019; Yeung, 2021). However, where GPN literature tend to use mostly qualitative methods to elaborate the mechanism, this study

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[3] This dynamic path of development of latecomers is also explored in the context of business schools in Asia as latecomers trying to learn from the schools in incumbent countries but also seeking their own path eventually (Yoon et al 2021).

adopts a quantitative, patent data-based, measurement of the mechanism of knowledge localization creation and ownership.

The next subsection will discuss a detailed aspect of measurements and specific hypotheses related to the mechanism.

3) Three Aspects of the Local–Global Interface and Hypotheses

Given the discussion above, we proposed three aspects of local–global interface as the key factor of the upgrade and of RIS in emerging economies.

First, this study proposes to determine the specific pattern of dynamic changes in the role of foreign knowledge at the regional level. Specifically, given that the highest per capita income is recorded in Taipei and the lowest is in Penang, we hypothesized that Taipei would show a high and increasing level of intraregional knowledge localization and a low and decreasing level of internationalization (or the degree of relying on foreign knowledge). As a rapidly upgrading region, Shenzhen would correspond to an increasing level of intra-regionalization and a decreasing level of internationalization. This pattern of decreases in internationalization correspond to the decreases in backward participation at GVC measured by the share of foreign value-added in gross exports (Lee et al., 2018).

For this purpose, this study develops its own measures of RIS and focuses on three dimensions, namely, intraregional, interregional, and international. This approach is different from the two-dimension approach in NIS, which is divided into intranational and international only, i.e., the former is the exact residual or opposite of the latter. Unlike an NIS study, RIS analysis needs another dimension, namely, the interregional dimension of one region's reliance and interaction with other regions in the same nation. As such, this study considers this interregional dimension of how much a region relies on or interact with other regions in the same nation. In general, on the basis of a similar logic described above, one may hypothesize that an advanced or catching-up region would show a high or increasing level of inter-regionalization (a high or increasing citations to patents by other regions). We measured these variables by exploring the citation patterns of all patents with the inventors' addresses in localities, regardless of legal ownership, that is, foreign or local ownership.

Second, this study focuses on the role of local/foreign ownership of patents representing knowledge creation and diffusion. This dimension becomes important because simply relying on foreign-owned knowledge (patents) is insufficient in sustaining the upgrade to the later stages as foreign firms become increasingly reluctant to transfer or sell their technologies to latecomers who are catching up and getting close to the frontier (Lebdioui et al., 2021; Lee et al., 2021b). Amsden and Chu (2003) recognized this point in their study on Taiwan. They emphasized that one of the factors for Taiwan to join the ranks of high-income economies beyond the middle-income stage is its ability to create a critical mass of locally-owned firms, although it used to rely on FDI at its early stage of development.

In this sense, South Korea and Taiwan share the common formula for successful upgrades; therefore, economies attempting to catch up should acquire an indigenous technological capability (Mazzoleni and Nelson, 2007). We will be looking at Shenzhen and Penang from this perspective or in comparison with Taipei when we examine the extent and trend of ownership of patents filed in each region.

Thus, our analysis tests the hypotheses that Taipei has a high level of local patent ownership or a high share of patents filed by locally owned firms, and that Shenzhen shows an increasing share of locally-owned patents compared with that of Penang. One of the causes for the slow catching up of Penang, even though it started earlier than Shenzhen, is its failure to enhance the degree of local ownership in its innovation activities measured by patent ownership in this context. Similarly, Lee et al. (2021b) emphasized local ownership when they compared the automobile sectors in Malaysia, Thailand, and China with those in South Korea; one of the reasons for the slow or limited upgrade of the automobile sector in Thailand is explained in terms of the continuing dominance of Japanese ownership of auto firms, which are different from the cases of China and South Korea.[4]

The third and last aspect of the local–global interface is represented by measuring the variable of originality. Originality was first proposed to refer to the degree that an innovation (patent) combines knowledge from diverse fields (Hall et al., 2001; Trajtenberg et al., 1997). Thus, it represents a degree of knowledge convergence and combination. Cross-country growth regressions (Lee, 2013: Ch. 3) determined that originality is high in advanced economies but not that high in the catching-up economies of South Korea and Taiwan. More importantly, no robust relationship exists between the high originality and economic growth of countries.

This study addresses a similar observation at a regional level. If a region's economy and innovation are dominated by foreign MNCs from advanced economies, its level of originality is higher than that of other regions dominated by locally-owned firms. Specifically, we examined whether Penang, which is continuously dominated by MNCs, shows a higher level of originality than Taipei or Shenzhen because the latter regions are now increasingly dominated by indigenous firms. A related interpretation is that such a high level of originality and a slow upgrade degree in Penang is consistent with a previous national study (Lee, 2013: Ch. 3).

4. Measurement and Analysis

1) Patent Data

The patent data used in this research are originally from the USPTO. Specifically, the USPTO Patent Grant Red Book provides a variety of information about patents, such as patent number,

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[4] Indeed, the mixed success or failure of the auto sector in Malaysia despite the strong local ownership is explained by referring to the lack of discipline in either domestic or world market (Lee et al., 2021b).

inventors' information, assignees' information, fields that patents belong to, citation information, and filing date. After the bulk patent data granted from 1976 to 2017 from the USPTO Patent Grand Red Book is downloaded, a data mining process is applied using the SAS program in accordance with the method suggested by Potter and Hatton (2013) and adopted by Lee et al. (2021a). In cleaning up the data, information available from several patent data sets is utilized: NBER patent data set (1963–1999 and 1976–2017) and the United States Patent Data set (1926–2010) compiled by professor Stoffman and used in a previous study (Kogan et al., 2017),[5] USPTO Patent and Citation Data (Sampat, 2011), and Disambiguation and Co-authorship Networks of the U.S. Patent Inventor Database (Lai et al., n.d.) in Harvard Dataverse. These data sets are also constructed using the USPTO Patent Grand Red Book.

2) Intra-regionalization, Inter-regionalization, and Inter-nationalization

In NIS analysis, one focal variable is a variable called knowledge localization (Jaffe et al., 1993), which measures the degree of local creation and diffusion of knowledge in a country. The opposite of this variable is internationalization, which refers to the degree that innovation (patents) in a country relies on foreign knowledge. Although knowledge localization is equivalent to 1 minus internationalization in a country, a regional level analysis requires the additional dimension of inter-regionalization, which refers to the degree that a region's innovation interacts with or relies on innovation in other regions in the same nation.

In this study, regional level analysis uses the following variables to represent the nature of innovation in a region: intra-regionalization, inter-regionalization, and internationalization of knowledge. These three measures should be summed up to be one because a patent from a region cites a patent from the same or different region in the same nation or a patent from other nations. Therefore, the three measures can be defined as follows:[6]

$$Intra-regionalization_{xt} = \frac{n_{xxt}}{n_{xt}}, \qquad \text{(1-A)}$$

$$Inter-regionalization_{xt} = \frac{n_{xx't}}{n_{xt}}, \qquad \text{(1- B)}$$

$$Internationalization_{xt} = \frac{n_{xdt}}{n_{xt}}, \qquad \text{(1- C)}$$

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[5] Noah Stoffman, Associate Professor of Finance & Weimer Faculty Fellow in Keeley School of Business, Indiana University.

[6] Given that the three measures are summed up to be one, for the purpose of the analysis, normalization using the concept of control patents proposed to control the size effect is unnecessary (Jaffe et al., 1993).

where n_{xt} is the common denominator representing the total number of citations made by all patents invented in a region x' granted in year t. In Equation (1-A), n_{xxt} is the total number of citations to the patents invented in a region x made by the patents invented by region x and granted in year t. In Equation (1-B) $n_{xx't}$ is the total number of citations made to the patents invented in other regions (x') in the same nation made by all the patents from a region x. In Equation (1-C), n_{xdt} is the number of citations made to the patents invented in foreign nations (d) made by region x's patents granted in year t.

Figure 3 shows the extent and trends of the intra-regionalization index of the three regions. As expected from the hypotheses in the preceding section, the level of intra-regionalization in Taipei is much higher than that of Shenzhen and Penang. In the meantime, Shenzhen and Penang have an increasing pattern, which is consistent with their increasing per capita income that is catching up steadily with the US level over time (Figure 1). The degree of intra-regionalization in Taipei has increased from 4% in the 1980s to >10% in the 2000s, indicating about 10% of self-citation rates at the regional level. By contrast, the level of intra-region self-citation in Shenzhen or Penang is only half of the level in Taipei or 6% in Shenzhen and 4% in Penang in the 2010s. Less than 10% of intra-regionalization implies that the majority of citations by these regions are attributed to foreign patents. This finding is expected for a region in EEs, so internationalization is also measured in this study.

Figure 4 illustrates the extent and trends of internationalization (Equation 1-C), namely, the degree that patents by inventors in the region tend to cite foreign patents, namely patents with inventors' addresses in foreign nations. As we expect and hypothesize, the internationalization or reliance on foreign patents of Taipei clearly decreases, which reflect the enhancement of its own indigenous technological capabilities and RIS. The absolute degree of internationalization decreased from 95% in the early 1980s to less than 82% in the early 2000s although it increased back slightly in the 2010s. By contrast, this trend is unclear in the cases of Shenzhen or Penang, and their level of internationalization remained higher than 90%. However, the level of Shenzhen is lower than that of Penang. This finding is consistent with a higher level of development or catching-up by Shenzhen than that of Penang.

One interesting pattern in the case of Taipei is that around the mid 2000s its intra-regionalization stopped increasing but decreased slightly since then, whereas its internationalization stopped decreasing but increased slightly since then (Figures 3 and 4). This inter-connected pattern is exactly consistent with the hypothesis of 'In-Again" with GVC after the stage of 'Out' from the GVC, or recoupling with GPN after the stage of decoupling (Lee et al., 2018). In other words, local firms would want to open again and globalize after they build a certain level of indigenous capabilities and domestic value-added and chains during the preceding stage of the 'out' from GVC or decoupling from GPN. Or, while a certain high level of intra-regionalization is desirable, the degree of intra-regionalization cannot increase unlimitedly, which cannot make sense. The opposite is true of internationalization.

Last, Figure 5 presents the extent and trend of inter-regionalization, which is the degree that a region's innovation relies on knowledge from other regions in the same nation. The extent of Taipei is higher than that of the two other regions and even rapidly increasing over time although it experiences some changes in the 2000s. In the 2010s, the degree of the inter-regionalization of knowledge in Taipei is higher at 6% or less than 2% levels in Shenzhen or Penang. However, at low levels, both Shenzhen and Penang show an increasing trend, and the level in Shenzhen is consistently higher than that of Penang. These patterns agree with the hypotheses in the preceding section.

[Figures 3, 4, and 5]

(3) Local Ownership of Innovation in a Region and Originality

The next question is the degree of the indigenous ownership of innovation made inside a region because some innovations (patents) are filed by an inventor in a region, but this inventor may be hired by a foreign or domestic firm in the region. Thus, the variable of the local ownership of innovation measures the share of patents owned by indigenous firms out of all the patents invented in a region (with inventors' address in the same region) assigned to firms of all kinds of ownership. It can be defined as follows:

$$Local\ ownership = \frac{N_{cxt}}{N_{xt}},$$

where N_{cxt} is the number of patents invented in a region x and assigned to a firm with its nationality in the host country c, and N_{xt} is the total number of patents assigned to any firm and invented in a region (with the first inventor address located in region x) granted in time t.

Figure 6 shows the time trend of the local firm ownership of three regions. The shares in Taipei have reached almost 100% by the mid-2000s from about 40% in the 1980s. The share of the local ownership in Shenzhen reached the similar level by the mid-2010 within a shorter period because the share used to be close to zero in the mid-1990s. By contrast, the local share in Penang did not show such a sharp increase, but it has remained around 10% since the 1990s.

Figure 7 presents a more detailed picture by looking at the cross-country decomposition of the top 10 assignees in each region. The trends in Taipei have confirmed the dominance by the Taiwanese firm since the mid-1990s. In Shenzhen, the share of domestic or Chinese-owned firms in the top 10 assignees has kept increasing since the late 1990s and reached almost 100% in 2013–2015. This finding is matched with the decrease in the shares by the US and Taiwan. Unlike Shenzhen and Taipei, Penang has remained dominated by the US firms with 50%–70% shares since the 1990s. This value is matched with the decrease in the shares by the Malaysian firms from 20% to zero in the mid-2010s.

Further detailed information about the specific names of the top firms in each region since the 2000s is available in the Appendix Tables for Shenzhen and Penang. In Shenzhen, the two Taiwan-origin firms, namely, Hong Hai Precision and Foxconn, ranked as the top 1 and 2 in 2005. In 2011, the top 4 ranks are dominated by the indigenous Chinese firms, such as Huawei, followed by the Taiwanese firm, Hong Hai Precision, which ranked the fifth. By 2015, all the top 10 firms became filled by the Chinese-owned firms led by ZTE followed by Huawei. The Appendix Table shows that Penang has remained dominated by the US firms, including Intel, Motorola, and Altera.

Taipei and Shenzhen have steadily reduced their dependency on foreign firms' knowledge, which is contrary to Penang. The considerable creation of knowledge by the indigenous firms in Shenzhen seems to be one of the reasons for Shenzhen to make an upgrading transition from a peripheral to catching-up the RIS than that in Penang. The increased indigenous knowledge in Taipei and Shenzhen becomes the knowledge pool in the region and likely affects the increase in the intra-region and inter-regional localization of knowledge, as shown in the preceding subsection.

The dominance of foreign MNCs in Penang is possibly related to the highest degree of originality in Penang (Figure 8). Originality measures how many various fields (classes) of knowledge are used and thus cited to invent a patent; it is defined as follows (Hall et al., 2001; Trajtenberg et al., 1997):

$$Originality_i = 1 - \sum_{k=1}^{N_i} \left(\frac{NCITED_{ik}}{NCITED_i}\right)^2,$$

where k is the patent class, $NCITED_{ik}$ is the number of citations made by the patent i to patents belonging to patent class k, and $NCITED_i$ is the total number of citations made by patent i. To transform this variable into a regional level variable, after calculating the originality of each patent, we average the values of originality over all the invented in a region.

Given that the patents filed by high-income countries tend to show a high degree of originality (Lee, 2013: Ch. 3), it is not surprising that Penang's patents show a high originality.

(Figures 6, 7, and 8)

4) Decentralization of Innovator Distribution and Technological Diversification

Finally, we look as the two measures of RIS, and these two variables also used to be measured at national level in the NIS literature, that is, technological diversification and concentration (or decentralization) of innovation activities across assignees.

First, technological diversification refers to the number of diverse fields of technologies a region/nation has filed a patent for and can be defined as follows (Lee et al. 2021a; Lee, 2013):

$$Diversification_i = \frac{N_i}{total\ number\ of\ classes},$$

where N_i refers to the total number of technological classes that patents from region i are registered (namely in how many diverse fields a region has filed the patents), and the total number of classes in the patent systems can be determined at several levels, such as 3 or 4 digits. The number in the U.S. patent classification system was 473 classes at the three-digit level in 2019. The degree of technological diversification is high in developed NIS (Lee, 2013; Lee et al., 2021a). The same measures at a regional level (Figure 9) also show that the diversification level is positively related to the per capita income of regions. The highest level (0.5) is observed in Taipei, followed by Shenzhen (~0.3) and Penang (<0.1). With a 0.5 level, Taipei has registered its patents in about half of the 473 classes.

The decentralization or concentration of innovation measures the degree of even or uneven distribution of innovators (patent assignees and legal owners of patents), i.e., whether innovation is conducted by a large number of firms or dominated by a few large firms. Thus, Herschman–Herfindahl index (HHI) can be measured with the following formula (Lee, 2013):

$$HHI_{xt} = \sum_{i \in I_x} \left(\frac{N_{it}}{N^*_{xt}}\right)^2,$$

where I_x is the set of assignees, N_{it} is the number of patents filed by assignee i in year t, and N^*_{xt} is the total number of patents filed by region x in year t, excluding unassigned patents.

To easily reflect the idea that even or dispersed ownership of innovation is the conventional fact in high-income economies (Lee, 2013), we set $(1 - HHI_{xt})$ to refer to the degree of the decentralization of innovation over assignees in region x in time t (Lee et al., 2021a). We also use an alternative measure defined using the share of the top five assignees in the total number of patents invented in a region with the following formula:

$$TOP5_{xt} = \frac{N_{5xt}}{N_{xt}},$$

where N_{5xt} is the number of patents assigned to the top five assignees among patents granted in region x at year t, and N_{xt} is the total number of patents granted in region x at year t. Accordingly, $(1 - TOP5_{xt})$ is the degree of the decentralization of patent ownership.

In Figure 10A, the level of innovation decentralization, represented by $1 - \text{HHI}$, is the highest in

Taipei, whereas the levels of innovation decentralization in Shenzhen and Penang are catching up rapidly with that of Taipei. However, if we refer to an alternative measure of (1 – TOP5), such degree of catching-up is not that obvious. In other words, approximately 20%–30% only of the patents invented in Taipei are owned by the top five assignees. Conversely, the degrees in Shenzhen and Penang are approximately 50% and 60%, respectively. Interestingly, in both measures of decentralization, the difference between Shenzhen and Penang is not that large.

(Figures 9 and 10)

5. Alternative Models of Catching-up RIS and Policies

Following upon the empirical analysis verifying the hypotheses, the current section addresses the burning question of ‘how’ Shenzhen following Taiwan has been able to promote locally owned firms out of their interaction with and learning from foreign MNCs. By comparison, Penang is more slowly catching up and has remain reliant on MNCs. Broadly, the question of ‘how’ can be placed in the context of a larger question of how to sustain economic growth in emerging economies, thereby overcoming the possibility of the MIT.

As the source and solution for the MIT, previous studies such as the ADB-sponsored study of Eichengreen et al. (2013, 2012) and Lee (2013) observed that innovation capabilities are the key binding constraints for the MIT. This view is also consistent with the early statement by the World Bank that middle-income economies tend to fall under a trap because they get caught between low-wage manufacturers and high-wage innovators; their wage rates are too high to compete with low-wage exporters, and the level of their technological capability is too low to enable them to compete with advanced countries (World Bank, 2010). So, the solution to the MIS is innovation. However, this diagnostics and solution of MIT do not address the issue of ownership of innovation, namely, who emerges as the carrier of innovation. In contrast, the current study has identified emergence of local ownership as one of the important and interesting aspects differentiating the fast catching up in Shenzhen versus the slow catching up in Penang. Subsequently, we provide elaboration of how each of the region behaved differently in terms of promotion of local ownership, and thereby propose the three regions as alternative models of catching up RIS in terms of the local–global interface.

First, the Taipei model can be characterized by a high degree of intra-regionalization and the lowest degree of inter-nationalization (Section 4). However, Taipei was also used to be dominated by foreign MNCs and faced a crisis as the foreign vendor switched to other lower-wage economies, such as Malaysia, for their OEM orders (Li et al., 2016; Amsden and Chu, 2003: 70-79), as the wage rate increased in Taiwan in the 1980s. This phenomenon is the typical symptom of MIT. In this situation, many engineers who used to work in a foreign-owned television factory left the firm to start their own firms in related areas (Amsden and Chu, 2003, p, 23-24). For them, the source of technology have changed from FDI to technology licensing agreement with foreign entities. Eventually, a more effective model have appeared, and that was a combination of firm-level R&D effort and supportive industrial/innovation policy by the government, including public–private collaboration (Lebdioui et al., 2021; Lee et al., 2021b; JD Lee et al., 2021).

Specifically, public research organizations, such as Industrial Technology Research Institute (ITRI), play a role of a "new developmental state" because they develop high-tech part and components that were formerly imported and had private firms to produce them (Amsden and Chu 2003, p. 77). Furthermore, for an important upgrading transition from making small (analog) calculators to laptop PC, ITRI led the public–private R&D consortium to develop a common machine architecture for laptop PC and its prototypes, which can be easily translated into a series of standardized components produced by manufacturers through mass production. The consortium represented a watershed after some previous failures, indicating the potential of R&D consortium to help establish new "fast follower" industries (Mathews, 2002). Despite collaborative relations with foreign entities for technology licensing, the acquisition of innovation (design) capability required an active learning effort from the Taiwan side. For instance, in making circuit chips, Taiwanese engineers went around the world to study large-scale integration applications. Eventually, by combining their observations and knowledge gained from Japanese suppliers, they became good at integrating a large number of parts and components sourced globally at the lowest prices into a small space (Amsden and Chu 2003, p. 28–32).

Second, the Penang mode is somewhat opposite to the Taipei mode in terms of the continuing dominance of foreign MNCs in production and innovation. In the past, MNCs have been attracted to Penang's low-cost wages and tax haven. Despite the increasing income and wage rates, the share of MNCs in the total investment ranged from 60% to 70% from 2014 to 2015. It also fluctuated but had no clear declining trend; conversely, the local one contributed approximately 30% to 40% in the same period (Figure 5 in Lee et al., 2020). The new cycle of development is emerging, and the economy of Penang has been diversified from labor-intensified manufacturing operations to high-value-added manufacturing, including services from them, such as software, engineering design, R&D, and industrial system-based services, as well as new servicing industries, such as medical tourism, education, and shared service centers (Economic Indicators, 2015: 10–15). These structural changes have also been a response to the rise of China as an alternative location for MNCs (Diez and Kiese, 2006).

Penang witnessed some downsizing and exit of MNC manufacturing operation and merger and acquisition among multinationals to rationalize their resources and reduce redundancies over the past few years.[7] However, many MNCs maintained certain operations in Penang, as they are provided with

[7] Multinationals, such as Seagate Technology and Fairchild, are among the exit companies that may

strong supply chains, allowing them to produce advanced technologies and services. Some locally owned firms have emerged to advance their high value-added activities in Penang (Diez and Kiese, 2006; Lee et al., 2020). They include Vitrox (a HP spin-off that produces automated machine inspection vision systems), Globetronics (an Intel spin-off that provides semiconductor process services), and EngTek (from a 1970 humble workshop providing services to MNCs to produce hard disk drive components and precision tools). A key factor of this positive scenario is a local institution that has enabled the training and upskilling of their local force, such as Penang Skill Development Center, a non-for-profit institution that provides technical knowledge and training program to engineers in this region (Lee et al., 2020).

Third, Shenzhen lies between Taipei and Penang in terms of the levels of per capita income and of intra-regional and international localization of knowledge (Figures 3 and 4) although it is closer to Taipei in terms of the share of the local ownership of innovation (Figure 6). The leading companies in terms of the number of patents are Huawei and ZTE (Appendix Table). How have these firms grown and become dominant? The answer, which is the same as for Taipei above, is a combination of firm-level R&D effort and supportive industrial/innovation policy by the government, including public–private collaboration (Yang 2015; Lebdioui et al., 2021; Lee et al., 2021b).

Specifically, the industrial policy in China has been termed as the "'trading market for technology" (Mu and Lee, 2005), i.e., the Chinese government used its huge bargaining power associated with the size of the Chinese market to require foreign joint venture firms to transfer important parts of technologies. A famous example is the indigenous development of fixed line telephone because of the technology transfer and diffusion from a JV, Shanghai Bell, with the Chinese side having 60% or majority of shares. The transferred key technologies were later diffused to the local R&D consortium to develop the Chinese-owned fixed telephone switches. This consortium transferred the technologies finally to ZTE, two other SOEs, and one private firm (Huawei) to be in charge of the actual production. When these four indigenous Chinese firms started to compete directly with JVs, the role of the Chinese government was to provide market protection and give financial and moral incentives for the adoption and use of domestic products (Mu and Lee, 2005; Xin and Wang, 2000).[8]

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lead to a high level of employee retrenchment. From January 2015 and June 2017, 6,136 employees are estimated to be affected by such exits by MNCs (Lee et al., 2020).

[8] The Ministry of Post and Telecommunications in China (MPT) organizes coordinating conferences every year to coordinate local telephone service authorities to purchase indigenous equipment, and these coordinating conferences are a turning point for the growth of the communication manufacturing industry in China (Xin and Wang, 2000). Under the People's Bank of China's encouragement, the China Construction Bank supplied Huawei buyer credit RMB (name of Chinese currency) 3.85 billion, which was 45% of the bank's total buyer credit in 1998 (Mu and Lee, 2005).

Shenzhen city, given its status as a SEZ, has enjoyed various privileges in various policy initiatives (Yang, 2015). In a different and most recent case of Tencent, the help of the local government was critical to guarantee funding from venture capital and other financial investors at the initial stage of growth (Breznitz and Murphree, 2011: 175–178). To strengthen the local firm ownership on knowledge, Shenzhen promoted the growth of local firms, such as Huawei and Tencent, by investing in universities and large research institutes (Zhang et al., 2016; Breznitz and Murphree, 2011; Yang, 2015). The Shenzhen municipal government made efforts to encouraging higher education and attracted advanced manpower in Shenzhen, where universities and URIs, such as Shenzhen University in 1983, Shenzhen Polytechnic in 1993, THU Shenzhen Tsinghua Research Institute, and research base of PKU, CAS, Chinese Academy of Engineering, Hong Kong University of Science & Technology, were established by providing incentives or benefits (Chen and Kenney, 2007). These initiatives must have helped a diverse and large pool of human resources from other regions in China and other countries to come to Shenzhen. For instance, Huawei runs R&D centers in Beijing, Shanghai, Nanjing, Shenzhen, Hangzhou, and Chengdu (Li, 2009).

Shenzhen proceeds R&D collaboration with other countries. Since 1999, Huawei has worked collaboratively with R&D labs in Texas Instruments, Motorola, IBM, Intel, Agere Systems, Sun Microsystems, Altera, Qualcomm, Infineon, and Microsoft; since June 2005, Huawei has 10 joint research labs. Huawei had global R&D centers in Bangalore (India), Moscow (Russia), Stockholm (Sweden), Silicon Valley (US), California (US), and Dallas (US) (Li, 2009). ZTE has 14 R&D centers worldwide, and 8 of them are located in China. ZTE R&D centers in China closely work with 50 local research institutes (Hu and Mathews, 2008).

The above discussion suggests that Taipei in Taiwan and Shenzhen in mainland China has been more active or aggressive in terms of the degree of public intervention than Penang in Malaysia, which might be one of the reasons for the different degree of the local ownership of innovation across three regions. Whereas the former two cities involved a direct intervention of public sector in specific R&D projects to help indigenous firms, the role of the public sectors in Penang seems to have been more in the matter of human capital development or re-skilling and up-skilling of workforce which is utilized by foreign MNCs.

6. Summary and Concluding Remarks

This study raises the question of “why” economic performance and growth trajectories differ among Taipei, Shenzhen, and Penang in Asia. The most developed region is Taipei, while the least developed region is Penang. Specifically, the research question is why Shenzhen is catching up fast with Taipei, whereas Penang is slowly catching up. From a Schumpeterian perspective, this paper answers this question of "why" by focusing on the divergent nature of RIS in three regions, specifically the local–global interface, which led to divergency in the degree and speed of the localization of knowledge creation and ownership. Specifically, the paper developed three-interrelated measures of the RIS, intra-regionalization, inter-regionalization, and inter-nationalization of knowledge, as well as the degree of local ownership of patents invented in a region.

First, the level of intra-regional and inter-regional localization of knowledge in Taipei is the highest, but its level of internationalization (or degree of reliance on foreign knowledge) is low and decreasing. Shenzhen has been replicating Taipei's trajectory more closely than Penang, which has been relying on foreign knowledge sources and slowly increasing the intra- or interregional localization of knowledge. Second, the main carrier and ownership of innovation in Taipei has shifted from foreign MNCs to indigenous firms, which have been closely replicated in Shenzhen since the mid-2000s. Conversely, Penang has rather deepened its reliance on foreign MNCs. Third, given the high dominance of MNCs, the value of originality in Penang is higher than that of Shenzhen or Taipei and this difference is one aspect of the quality of patents. Fourth, an increasing and high value of technological diversification is observed in Taipei, which is closely followed by Shenzhen, but not by Penang. Fifth, in terms of concentration of innovators, Taipei has the lowest value, whereas the difference between Shenzhen and Penang is not that clear. This result is consistent with findings that show no robust relationship between decentralization and economic catching-up (Lee, 2013: Ch. 3).

These findings helped in identifying and differentiating the catching up RIS. A dynamically catching-up RIS or upgrading process of RIS can be characterized by a steady increase in intraregional creation and diffusion of knowledge, a decrease in internationalization, an increase in the local ownership of innovation, and an increase in technological diversification, but not necessarily the decentralization of innovator distribution.

This study also addressed the issue of "how" the three regions have behaved differently in achieving a divergent degree of success and proposed the three regions as alternative models of catching up RIS in terms of the local–global interface. Taipei and Shenzhen are a mode of eventually creating indigenous firms. By contrast, the Penang model continuously relies on MNCs. Although the former model may be more difficult to realize, it has led to a faster catching-up than the slow catching-up mode of Penang. In terms of promoting locally-owned firms eventually, Taipei and Shenzhen have been more active or aggressive in terms of the degree of public intervention than Penang. While the former two cities involved a direct intervention of public sectors in specific R&D projects to help indigenous firms, the public sector in Penang focused on human capital development for the workforce hired in MNCs. This difference may be one of the reasons for the different degrees of the localization of knowledge creation and ownership across the three regions.

Although one limitation of this study is its reliance on patents, ignoring other measures of RIS, such as tacit dimensions of knowledge, it has achieved some contributions of revealing the importance of the local–global interface by developing new quantitative measures of that interface, focusing on the localization of knowledge creation and ownership. Given the generalizable importance of local knowledge and ownership congruent to the related literature, the findings from this paper may have policy implications appliable to other regions in the world.

If a latecomer region wishes to realize a fast catching up, then an emerging policy implication would be the paramount importance of eventually increasing the localization of innovation and its ownership beyond the initial stage of learning from foreign knowledge sources. In this regard, various policy initiatives that were adopted in Taipei and Shenzhen can be suggested as the means to promote indigenous innovation out of learning from foreign MNCs. Such initiatives include policies to promote spinoffs and startups by locals, technology transfers from foreign firms to domestic firms, public and private joint R&Ds, and in-house R&D centers by local firms, as well as policies to attract branches of universities and encourage academic spinoffs and venture financing for them.

While this research remains a case study, it successfully identifies and elaborates some stylized patterns or hypotheses that can be subjected to an econometric study involving a larger dataset in future studies. We are conducting a cluster analysis to classify as many as 30 cities around the world into several types, especially mature and fast and slow catching-up RIS, and these types can be subjected to a regression analysis following the method of Lee et al. (2021a).

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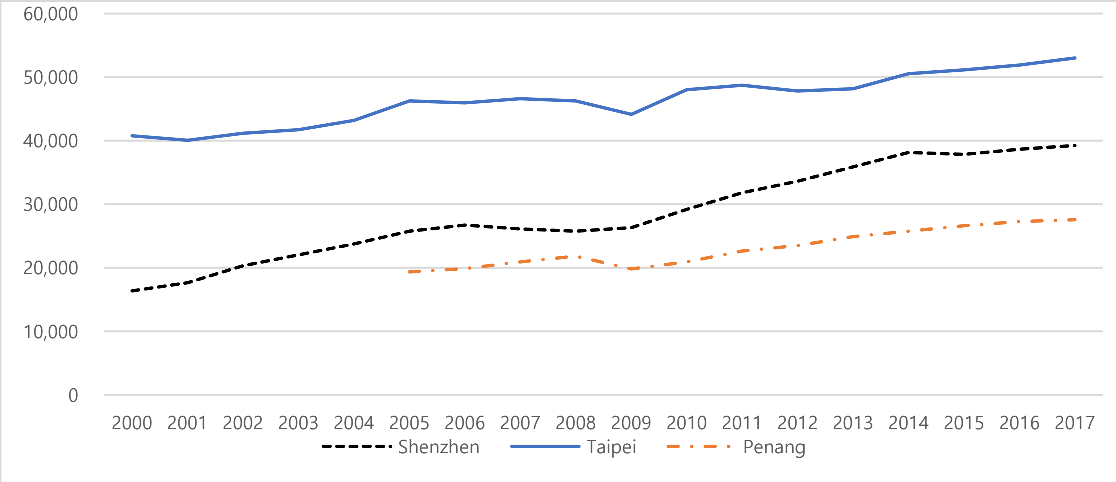
Table 1 Basic profile of Taipei, Shenzhen, and Penang, 2017

	Taipei	Shenzhen	Penang
Population	6,669,946 (2017) 6,214,370 (2000)	12,528,300 (2017) 7,012,400 (2000)	1,746,700 (2017) 1,332,700 (2000)
Area (km^2)	1,380.53	1,997.47	1,049
Per capita GDP USD (PPP)	53,013.78	39,244.69	27,569.08
Per capita GDP relative to that of the US (%)	96.75	71.62	50.31
Number of the US patents filed in 2017	3785	2491	112
Number of patents per million population	5670.03	1988.30	641.21
Cumulated number of patents (1994-2017)	57714	17085	1235

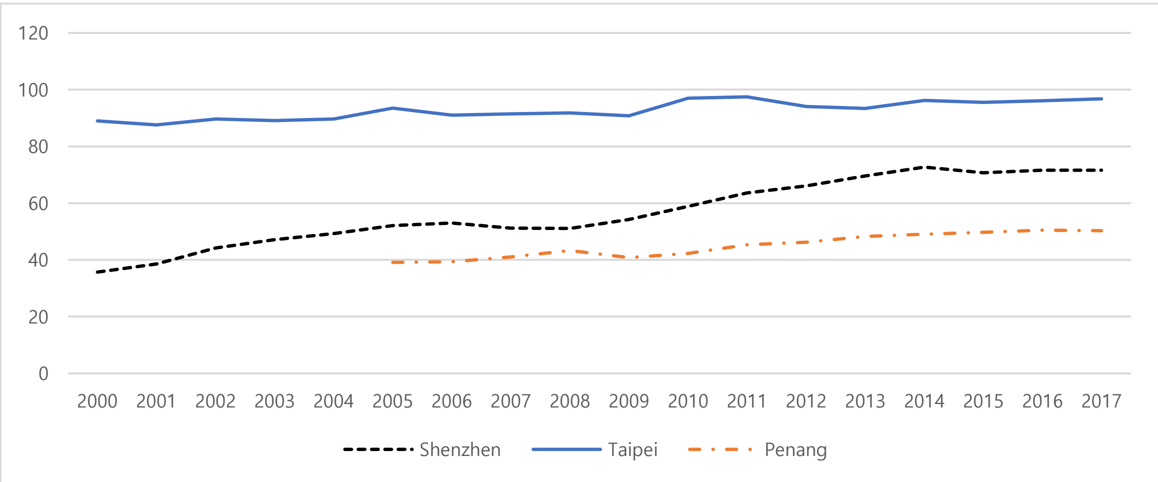
Source: Shenzhen Statistical Yearbook, Department of Statistics Malaysia Official Portal, Taipei City Statistical Yearbook, and Statistical Yearbook of new Taipei City, Taiwan National Statistics, Penn World Table 9.1, China Statistical Yearbook, Department of Statistics in Malaysia, and Author's calculation

Figure 1A: Per capita GDP (PPP, US$)



Source: Shenzhen Statistical Yearbook, Department of Statistics Malaysia Official Portal, Taipei City Statistical Yearbook, and Statistical Yearbook of new Taipei City, Taiwan National Statistics, Penn World Table 9.1, China Statistical Yearbook, Department of Statistics in Malaysia, and Author's calculation

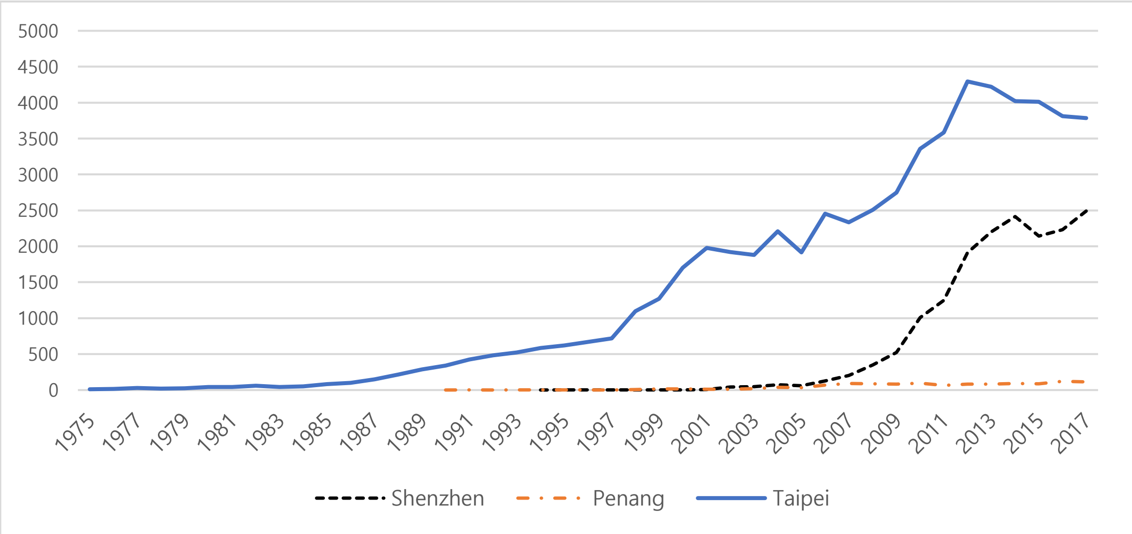
Figure 1B: Per capita GDP relative to that of the US



Source: Shenzhen Statistical Yearbook, Department of Statistics Malaysia Official Portal, Taipei City Statistical Yearbook, and Statistical Yearbook of new Taipei City, Taiwan National Statistics, Penn World Table 9.1, China Statistical Yearbook, Department of Statistics in Malaysia, and Author's calculation

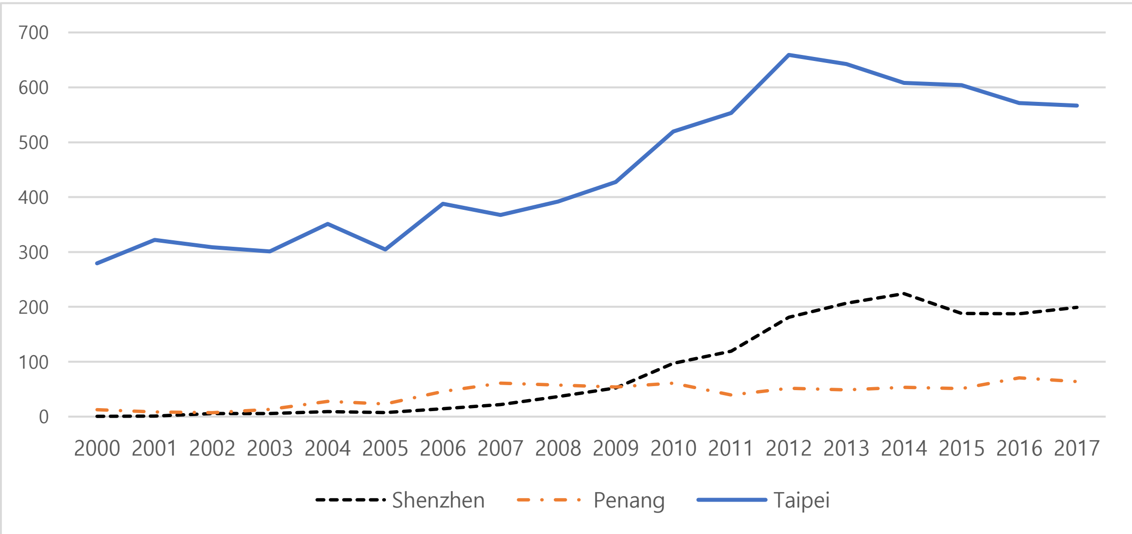
Figure 2: Patent counts

(A) The number of patents



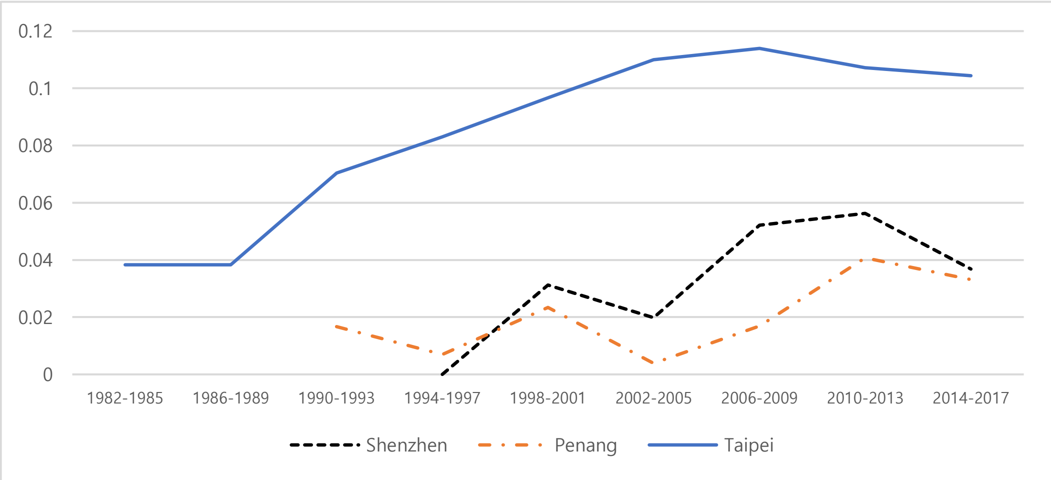
Source: USPTO & Author's calculation

(B) The number of patents per million population



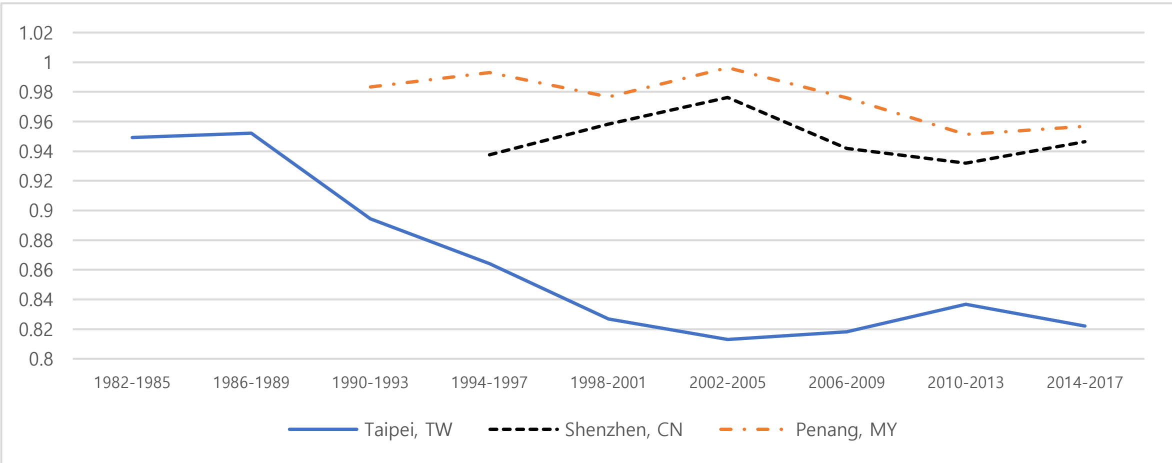
Source: USPTO & Author's calculation

Figure 3: Intra-regionalization



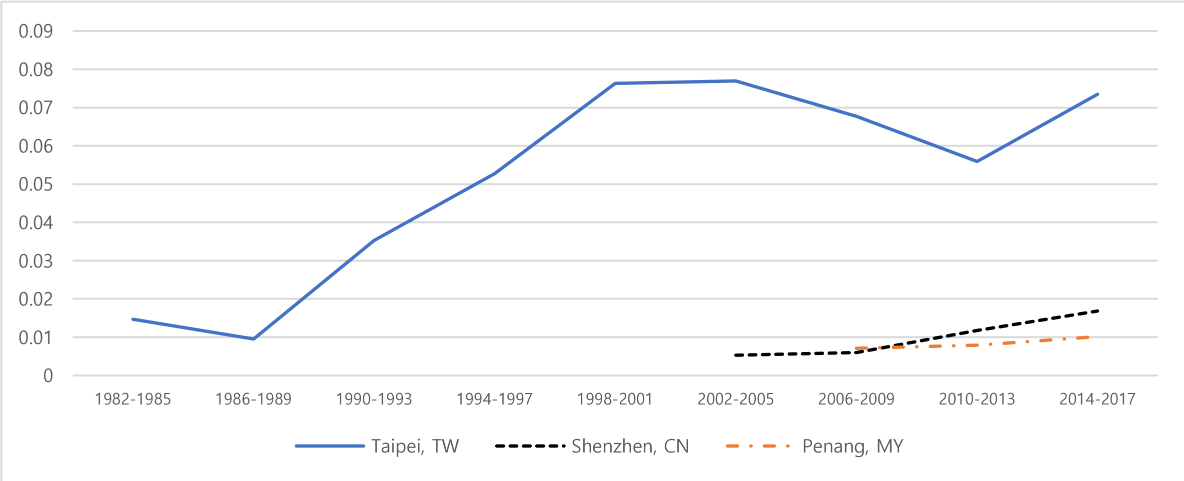
Source: Author's calculation

Figure 4: Internationalization



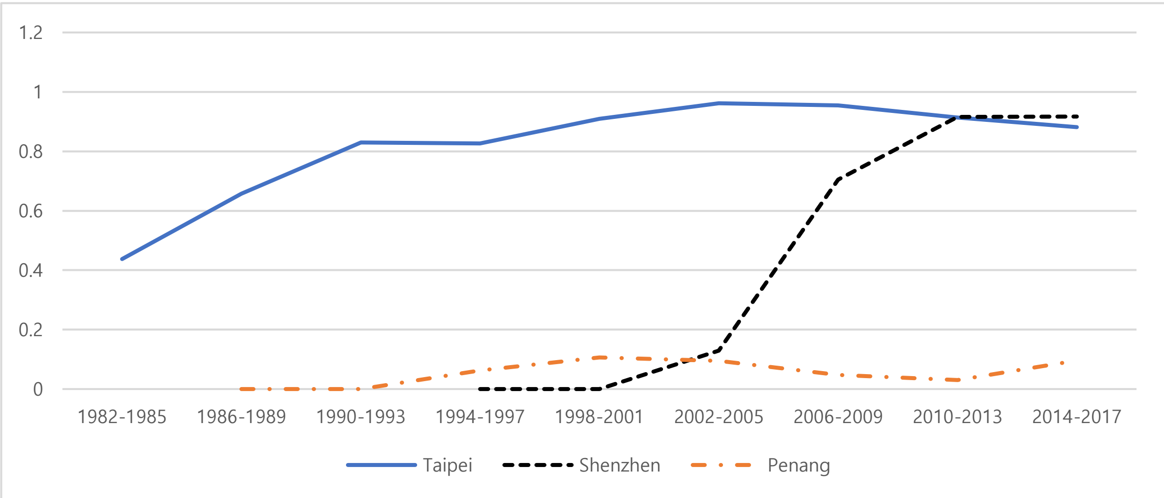
Source: Author's calculation

Figure 5: Inter-regionalization



Source: Author's calculation

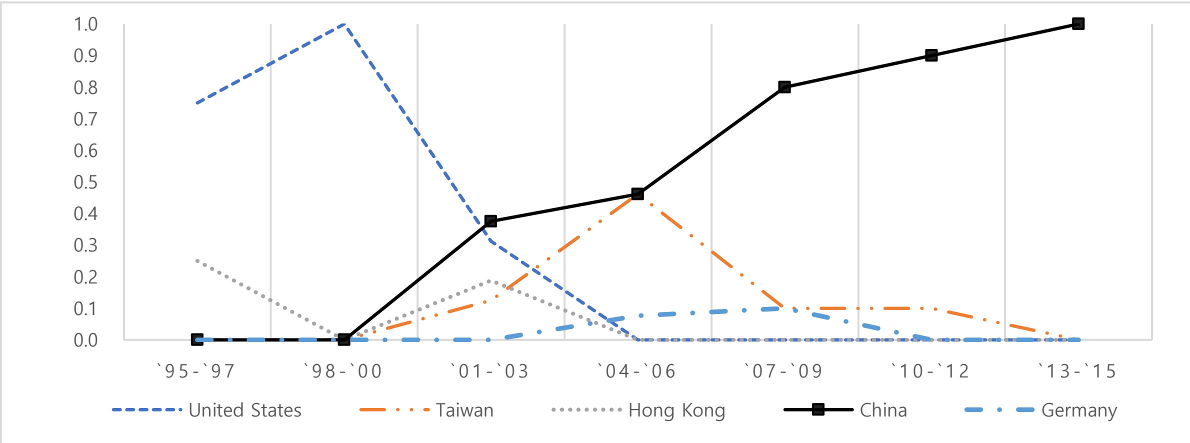
Figure 6: Local Ownership of Innovation



Source: Author's calculation

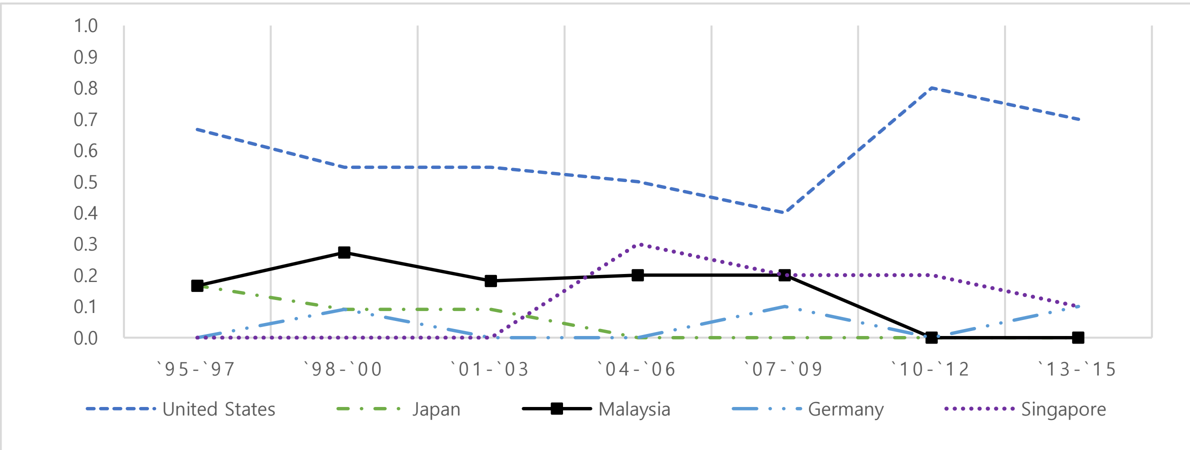
Figure 7: Shares by the Top 10 Assignees by the Origins

(A) Shenzhen



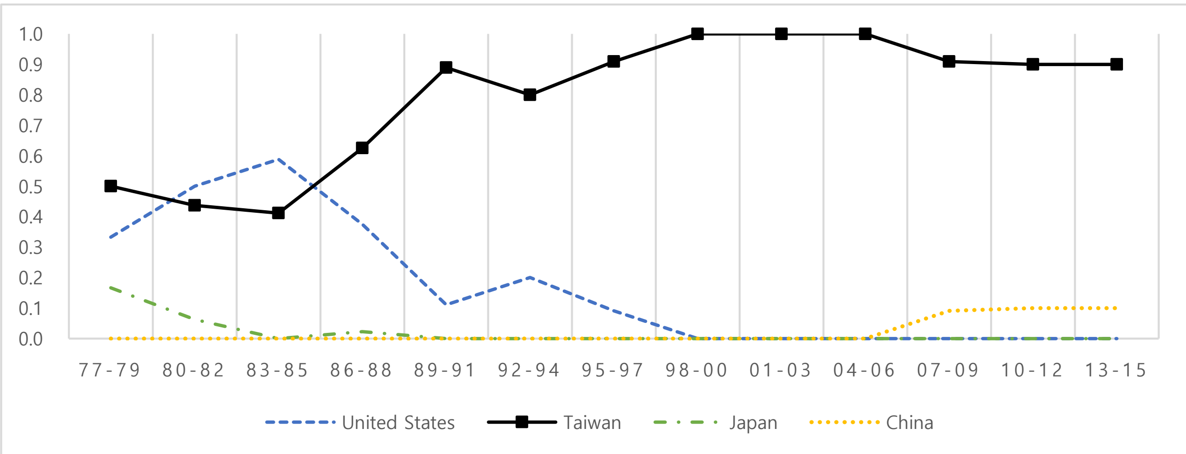
Source: Author's calculation

(B) Penang



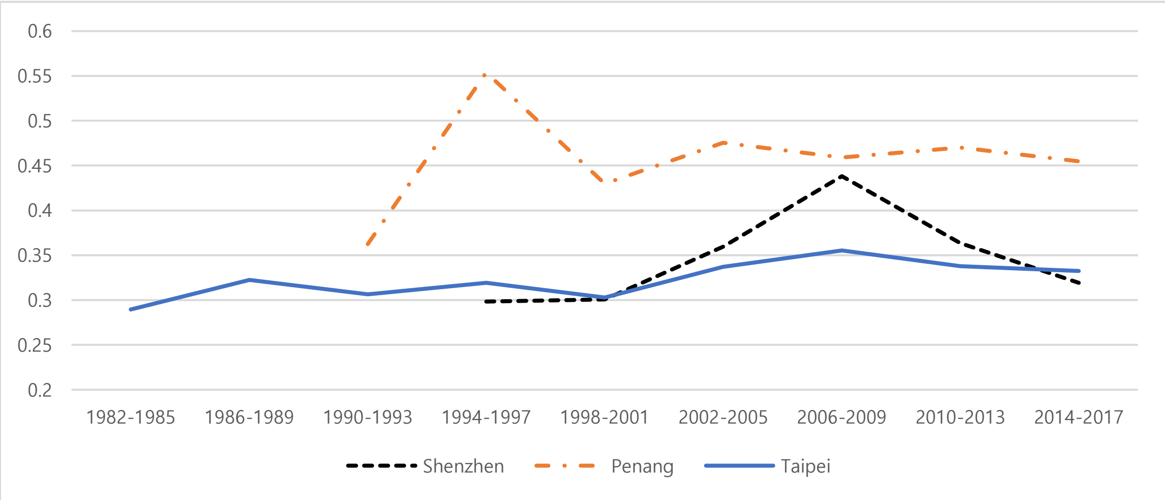
Source: Author's calculation

(C) Taipei



Source: Author's calculation

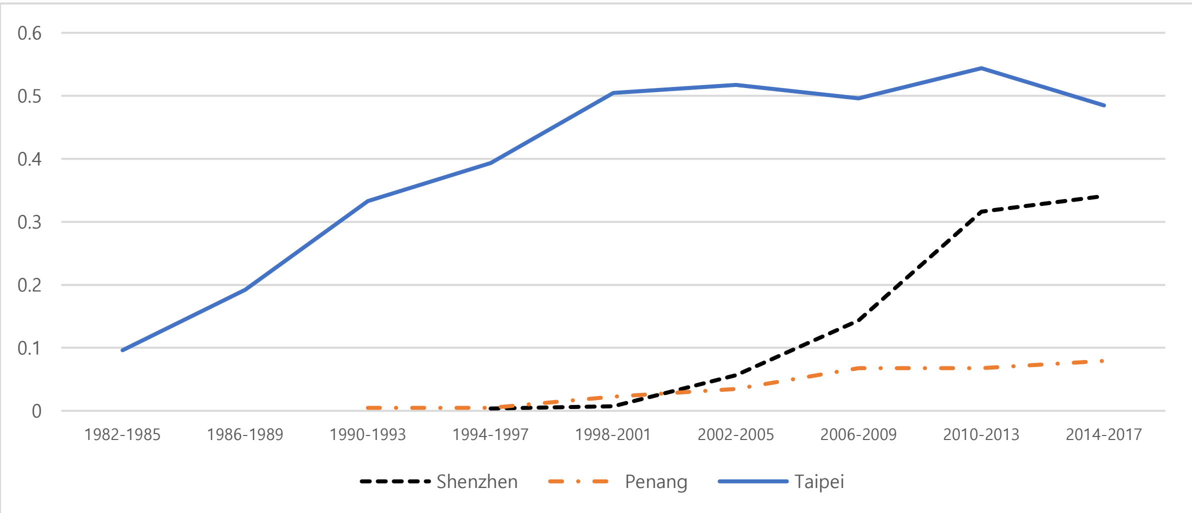
Figure 8: Originality (knowledge combination)



Source: Author's calculation

Notes: Average originality for the whole period is 0.463 for Penang, 0.344 for Shenzhen, and 0.334 for Taipei, respectively.

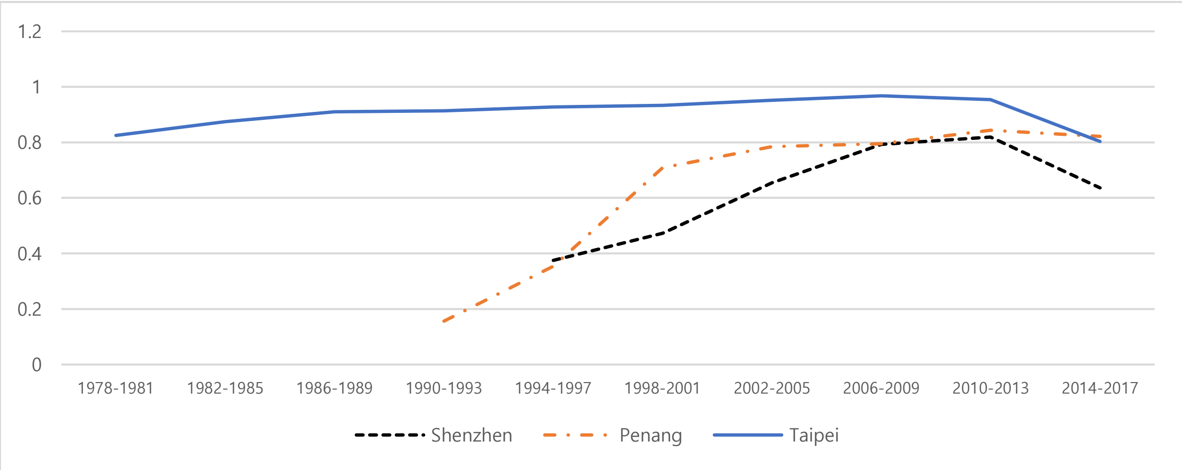
Figure 9: Technological diversification



Source: Author's calculation

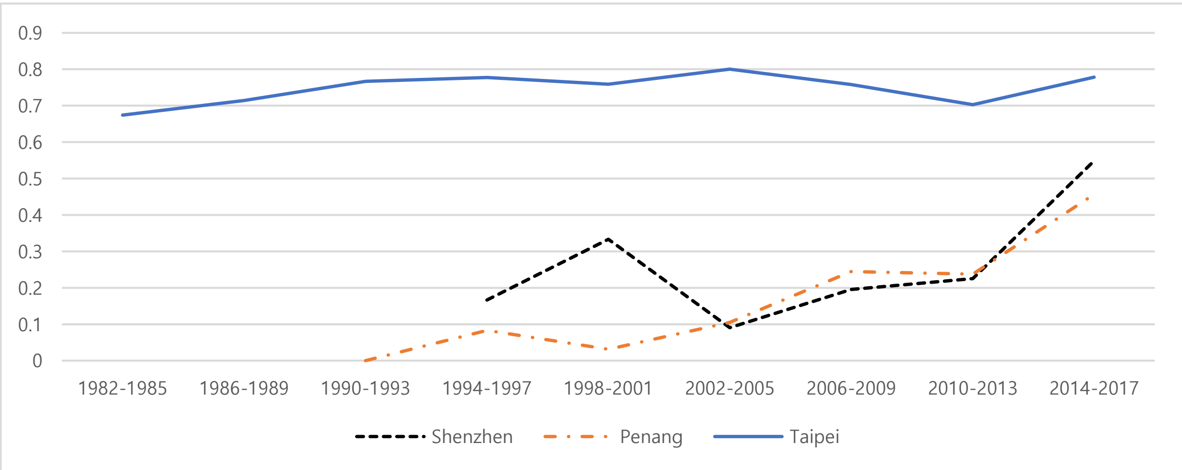
Figure 10: Decentralization of Innovator Distributions (Assignees)

(A) 1-HHI



Source: Author's calculation

(B) 1-(share of the top 5 assignees)



Source: Author's calculation

Appendix 1: Firm list of top assignees in Shenzhen, China

Grant year	Assignee	Assignee's country	Patents
2002	Hon Hai Precision Industry Co., Ltd.	TW	17
2002	Foxconn Precision Components Co., Ltd.	TW	14
2002	Shenzhen STS Microelectronics Co., Ltd.	CN	4
2002	Shanghai Jiao Da Onlly Co., Ltd.	CN	1
2002	Majorank International Limited	HK	1
2002	HotTowels LLC	US	1
2002	Shenzhen Hyper Technology Inc.	CN	1
2002	Shenzhen CIMC-Tianda Airport Support Ltd.	CN	1
2005	Hon Hai Precision Industry Co., Ltd.	TW	34
2005	Huawei Technologies Co., Ltd.	CN	6
2005	Crastal Technology (Shenzhen) Co., Ltd.	CN	1
2005	Orleans Furniture, Inc.	US	1
2005	Wok & Pan Industry, Inc.	CN	1
2005	Actherm Inc.	TW	1
2005	TCL King Electronics (Shenzhen) Co., Ltd.	CN	1
2005	Shanghai Jiao Da Onlly Co., Ltd.	CN	1
2005	Molex Incorporated	US	1
2005	Shenzhen LB Battery Co., Ltd.	CN	1
2005	Emerson Network Power Co., Ltd.	CN	1
2005	Phoenixtec Power Co., Ltd.	TW	1
2005	Cool Cubes, Inc.	US	1
2005	Fih Co., Ltd.	TW	1
2005	Liming Network Systems Co., Ltd.	CN	1
2011	Hong Fu Jin Precision Industry (Shenzhen) Co., Ltd.	CN	403
2011	Huawei Technologies Co., Ltd.	CN	296
2011	Fu Zhun Precision Industry (Shenzhen) Co., Ltd.	CN	122
2011	Shenzhen Fu Tai Hong Precision Industry Co., Ltd.	CN	97
2011	Hon Hai Precision Industry Co., Ltd.	TW	59
2011	Innocom Technology (Shenzhen) Co., Ltd.	CN	51
2011	Shenzhen Mindray Bio-Medical Electronics Co., Ltd.	CN	41
2011	ZTE Corp.	CN	25
2011	BYD Co. Ltd.	CN	24
2011	Ensky Technology (Shenzhen) Co., Ltd.	CN	8
2011	FuKui Precision Component (Shenzhen) Co., Ltd.	CN	8
2015	ZTE Corp.	CN	375
2015	Huawei Technologies Co., Ltd.	CN	349

2015	Shenzhen China Star Optoelectronics Technology Co., Ltd.	CN	332
2015	Hong Fu Jin Precision Industry (Shenzhen) Co., Ltd.	CN	173
2015	Tencent Technology (Shenzhen) Co., Ltd.	CN	116
2015	Fu Tai Hua Industry (Shenzhen) Co., Ltd.	CN	102
2015	Huawei Device, Co., Ltd.	CN	69
2015	BYD Co. Ltd.	CN	29
2015	Zhongshan Innocloud Intellectual Property Services Co., Ltd.	CN	27
2015	Shenzhen Fu Tai Hong Precision Industry Co., Ltd.	CN	26

Appendix 2: Firm list of top assignees in Penang, Malaysia

Grant year	Assignee	Assignee's country	Patents
2000	Altera Corporation	US	44
2000	Motorola, Inc.	US	42
2000	Intel Corporation	US	25
2000	Iris Corporation Berhad	MY	14
2000	Sony Corporation (JP)	JP	5
2000	Motorola Malaysia SDN BHD	MY	4
2000	Advanced Micro Devices, Inc.	US	3
2007	Avago Technologies ECBU IP (Singapore) Pte Ltd	SG	207
2007	Intel Corporation	US	152
2007	Altera Corporation	US	144
2007	Osram Opto Semiconductors (Malaysia) Sdn. Bhd.	MY	68
2007	Avago Technologies General IP (Singapore) Pte. Ltd.	SG	34
2007	Advanced Micro Devices, Inc.	US	18
2007	SilTerra Malayisa Sdn. Bhd.	MY	12
2007	Robert Bosch GmbH	DE	11
2007	Philips Lumileds Lighting Company, LLC	US	9
2007	Joinsoon Electronics Mfg. Co., Ltd.	TW	7
2007	Spansion LLC	US	7
2007	Micron Technology, Inc.	US	7
2007	Regent Medical Limited	GB	7
2010	Avago Technologies ECBU IP (Singapore) Pte Ltd	SG	185
2010	Intel Corporation	US	135
2010	Altera Corporation	US	130
2010	Fairchild Semiconductor Corporation	US	52
2010	eASIC Corporation	US	33
2010	Avago Technologies General IP (Singapore) Pte. Ltd.	SG	32
2010	Motorola, Inc.	US	28

2010	Spansion LLC	US	25
2010	Robert Bosch GmbH	DE	20
2010	Aptina Imaging Corporation	KY	20
2015	Altera Corporation	US	134
2015	Intel Corporation	US	108
2015	Avago Technologies General IP (Singapore) Pte. Ltd.	SG	89
2015	Flextronics AP, LLC	US	62
2015	Intellectual Discovery Co., Ltd.	KR	60
2015	INTELLISERV, LLC	US	42
2015	Motorola Solutions, Inc.	US	32
2015	Allegiance Corporation	US	29
2015	Robert Bosch GmbH	DE	26
2015	Spansion LLC	US	20